

Extreme Events Decision Making in Transport Networks: A Holistic Approach Using Emergency Scenarios and Decision Making Theory

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Abstract: This paper proposes a novel method to analyse decision-making during extreme events. The method is based on Decision-making Theory and aims at understanding how emergency managers make decisions during disasters. A data collection framework and an analysis method were conceptualized to capture participant's behaviour, perception and understanding throughout a game-board simulation exercise, which emulates an earthquake disaster scenario affecting transport systems. The method evaluates the participant's actions in order to identify decision-making patterns, strengths and weaknesses. A set of case studies has shown two typical patterns, namely: a) Support immediate rescue; b) Support lifelines recovery. Good decision-making practices regard to objective-oriented decision making, understanding of conflicting priorities and appropriate resource management. Weaknesses are associated with comprehending relationships between community/environment and projecting future scenarios. Overall, the case study's results demonstrate the efficiency and robustness of the proposed method to analyse decision making during disasters.

Key Words: *Disasters, Decision-making, Emergency management.*

1. INTRODUCTION

Natural and man made disasters affect communities on a frequent basis. Consequences range from loss of life to economic disruptions. The International Federation of Red Cross and Red Cross Crescent Societies (2002) estimates that the last decade alone accounted for 535,000 deaths and US\$ 684 billion in losses from direct damage to infrastructures and crops due to disasters.

In spite to great advances in various scientific areas, we still lack information on how people make decisions during crises. Disasters such as 1994 Northridge Earthquake (USA), 1995 Kobe Earthquake (Japan), 2004 Sumatra Earthquake and Tsunami (Asia) and 2005 Hurricane Katrina (USA) have been comprehensively reported. However, decision-making challenges faced by individuals during these disasters, such as resources availability, conflicting

priorities, information sharing, have been rarely studied in-depth. Many studies in transports have focused in developing systems for emergency management embedded with evacuation models and shortest paths algorithms (see examples from Cherrie & Dickson, 2006; Fu *et al.*, 2006; Liu, 1997; Liu *et al.*, 2006a; Liu *et al.*, 2006b; Takeuchi & Kondo, 2003; Kagaya *et al.*, 2005). Extensive literature is also found on specific issues such as network reliability, risk management and Information Technology applications (e.g. Geographic Information Systems for mapping, Dynamic Data Bases for information sharing). Their limitations are often associated with heavy data requirements, which are commonly unavailable in the immediate aftermath of events. Others authors have used decision-making theories to study improvisation during emergency events (Mendonça and Wallace, 2007, Mendonça *et al.*, 2001; Mendonça *et al.*, 2006), but findings are yet to be incorporated by the transport community.

Therefore, a gap in science and practice has been identified. Lack of information on how decision makers manage transport networks during stress-laden circumstances may impair on the understanding of decision making processes. This can ultimately be associated with poor performances or inappropriate responses. The understanding of how decision-making activities occur during crisis may gear organisations towards the development of theories and concepts for extreme events decision-making in transport networks.

Over the last few years, the authors have attempted to gather scientific data and understanding on decision-making during extreme events through emergency exercises observation. This was motivated by the fact that emergency exercises have already been widely used for disasters' preparation and training. Seven emergency exercises were observed in New Zealand using an observation method proposed by Ferreira *et al.* (2007). Throughout our observations, emergency processes and procedures applied in real situations were well understood, but above all it was observed that: a) exercises can simulate complexities observed in real events; b) personnel act similarly to real instances as learning opportunities rise from simulations; and c) Vast but unstructured knowledge can be acquired. Nevertheless, the high complexity of decision-making combined with limitations of the observation method highlighted the need to development a controlled experimentation method, in which specific situations could be simulated and data collected for further analysis.

This paper proposes a novel method to analyse decision-making during extreme events. The method is based on Decision-making Theory and aims at understanding how emergency managers make decisions during disasters. After this introduction, a data collection framework and an analysis method are introduced in the second section. Case study simulations are presented in the third section. Conclusions and findings are discussed in the last section.

2. DATA COLLECTION FRAMEWORK AND ANALYSIS METHOD

This section describes the background and conceptual elements used to design a role play game to simulate emergency scenarios. The following three sub-sections present the theory used to develop the game simulation, its operational background and the analysis method.

2.1 Theoretical Background and Design Protocols

The history of gaming can be tracked down back in 1962, when a PDP-1 (Programmed Data Processor-1) was used to develop simulations at the Massachusetts Institute of Technology

(McCarthy *et al.*, 2005). Since then, the most fascinating feature of games is their capacity to simulate scenarios and practice real-life situations. Fong (2006) reports numerous commercial games that have been adapted for military training, which focuses on the “use of information to alleviate the challenges in an urban warfare scenario” and ultimately understand “issues surrounding information requirement and usage, sense making, and command and control”.

We have defined a series of design protocols based on the findings from existing endeavours (The Virginia Department of Emergency Management, 2001), exercise observations and gaming theory. A key design protocol was to set a standard data collection procedure, which would be used along with an analysis method. Furthermore, data collection procedures had to focus on both quantitative and qualitative data in order to capture the various facets of decision-making during a disaster. Another important design protocol was the need to create a realistic and stimulating scenario capable of representing numerous complexities existing in real instances. Finally, the simulation experiment (or board game exercise) was designed to be of simple operationability as well to do not take too long in terms of time required.

Key game design features were defined as follows:

- Clear representation of transport networks due to our specific case study;
- Presentation of an urban area (e.g. hospital, parks, airport, commercial and administrative centres, central business district, residential areas, educational buildings etc);
- Easy reference system;
- Resources availability and deployment numerically represented;
- Resources movement and time restrictions to be applied to simulate stress and pressures common to emergency situations;
- Complex simulation of emergency scenarios;
- Variables of interest to be clearly isolated; and
- Limited to one hour in order to encourage people to take part in the simulation.

Conceptually, Naturalistic Decision Making Models were used to design the game simulation. In these models, it is assumed that decision makers are rational subjects who make use of general and specific knowledge and personal experiences. Knowledge and experience help in defining decisions as any action that will bring changes to the environment in a short and long term future.

Therefore, each road link or infrastructure asset in the game simulation is associated with pre-defined response objectives (e.g. Support immediate rescue, Protect private property, Support lifelines, Protect economy, Protect environment, Enable support from other areas, Repair key infrastructure and Facilitate access between communities). These have been defined in accordance with emergency exercise observations and represent how changes in the environment (i.e. physical deployment of resources) can delineate future instances.

2.2 Graphical Design and Simulation Operationability

The simulation was graphically designed using simple tools to create a board game, which is schematically represented in Figure 1. The board game is associated to a set of pre-defined events, which are called injects. Injects add data and information about the extreme event under simulation. Both the board and injects were developed in parallel to ensure consistency.

Rules were defined in order to make the game operational. The experiment is limited to a 25 minute period in which the participant can move available physical resources five times. Each resource deployment has to be done within a five minute period, which represents a response day. If resources are not utilized after five minutes, a *status quo* decision is considered. The simulation controller provides hardcopy inject-information to the participant at the beginning of each response day. The participant can also interact as much as he / she wants with the controller in order to acquire additional information.

Data is collected throughout the experiment by observing resource movements (quantitative data) and directly questioning the participant (qualitative data). After the given time of 5 minutes, data regarding the number of resources deployed to each location and the participant's reason to do so are recorded for further analyses. For instance, three units of resources deployed to road link 5 (quantitative data) in order to "support fire fighting access to industrial area and protect water resources for general public and hospital" (qualitative data).

Prior to the formal beginning of the simulation, the participant is asked to fill an Importance Matrix (Table 1), which records the relative weights for each response objective. A set of eight objectives were defined in order to support isolating variables of interest. In our case study, we were particularly interested in observing how the participant prioritizes its response in terms of human rescue (Support Immediate Rescue), economy (Protect Private Property and Protect Economy), critical systems (Support Lifelines and Repair Key Infrastructure), environment issues (Protect Environment) and transportation / commuting (Enable Support from Other Areas and Facilitate Accessibility between Communities). Thus, the participant should fill the blank cells in Table 1 using a given multi-criteria scale. It is done by cognitively estimating how more or less important each pair of items is in terms of the response process. To do so, two scales are proposed. If row items are considered more important than column items, the participant should use the scale given on the left hand side while the scale on the right hand side should be used when column items are judged more important than row items (see examples commented below). Upon the completion of the simulation, a semi-structured interview is conducted so further general information is collected in regards to the simulation.

Table 1: Importance matrix.

Items "i" \ Items "j"	Support Immediate Rescue	Protect Private Property	Support Lifelines	Protect Economy	Protect Environment	Enable Support from other Areas	Repair Key Infrastructure	Facilitate Accessibility Between Communities
Support Immediate Rescue	1							
Protect Private Property		1						
Support Lifelines			1					
Protect Economy			1/7					
Protect Environment					1			
Enable Support from other Areas						1		
Repair Key Infrastructure		5					1	
Facilitate Accessibility Between Communities								1

Scale to be used

Item displayed on rows of equal or more importance than items on columns
 1: Items "i" and "j" are of equal importance.
 3: Item "i" is slightly more important (or better) than "j".
 5: Item "i" is strongly more important (or better) than "j".
 7: Item "i" is much more important (or better) than "j".
 9: Item "i" is absolutely more important (or better) than "j".
 2, 4, 6 and 8: are intermediate values.

Item displayed on columns of equal or more importance than items on rows
 1: Items "j" and "i" are of equal importance.
 1/3: Item "j" is slightly more important (or better) than "i".
 1/5: Item "j" is strongly more important (or better) than "i".
 1/7: Item "j" is much more important (or better) than "i".
 1/9: Item "j" is absolutely more important (or better) than "i".
 1/2, 1/4, 1/6 and 1/8: are intermediate values.

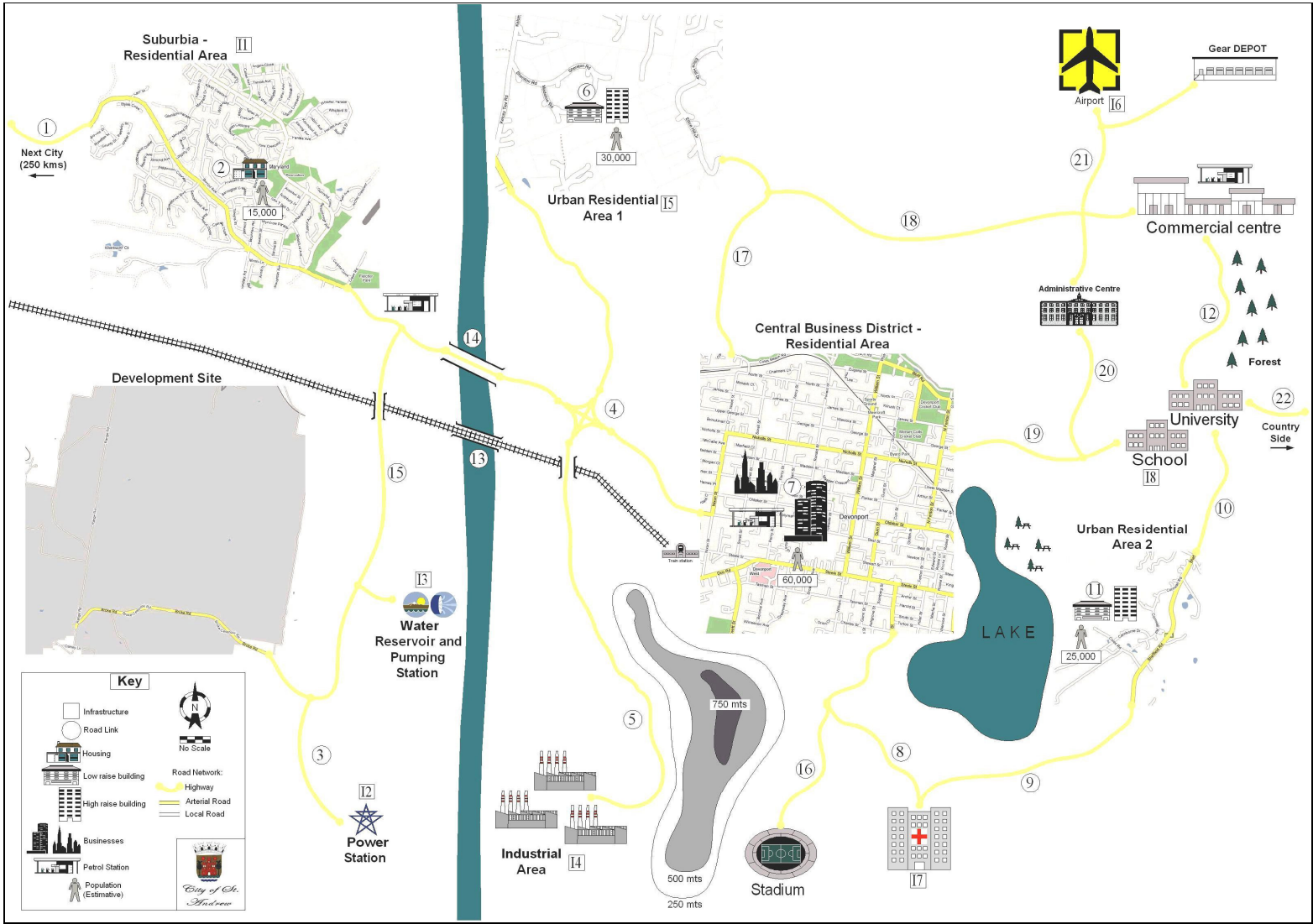


Figure 1: Board game.

2.3 Analysis Method

Simulation data is analysed to evaluate the participant's actions and identify decision-making patterns, strengths and weaknesses. Based upon Endsley's work (1995), we propose a four-step analysis of decision making during disasters (Figure 2). Step one and two focus on the analyses of planning and response, respectively. To do so, data from Importance Matrix and game simulation are used. The identification of the planning profile and the response conducted during the simulation (i.e. resources deployed) are compared in the third step in order to estimate a score. Score results along with planning profile and resources deployment are finally scrutinized in the last step. Each step is further specified as follows.



Figure 2: Analysis method.

2.3.1 Step I – Decision Making Planning:

This step focuses on the analysis of decision-making planning based on participant's personal knowledge and cultural paradigms plus the perception of the situation (disaster). Both knowledge and cultural background are explored using the Importance Matrix values, which capture goals/objectives as well expectations prior the simulation. The matrix is used to process final weights for response objectives using through pair-wise comparisons. A simple mathematical process (Eigen Vector) estimates objectives' weights. Consistency of pair-wise comparisons is checked using the Consistency Ratio (*CR*) defined by Saaty (1980) as shown in Equation 1. It is advised that *CR* value below 0.1 should be achieved for *n* greater than 4.

$$CR = \left(\frac{1}{RI} \right) \cdot \left(\frac{L_{max} - n}{n - 1} \right) \quad (1)$$

Where: *n* – number of items been compared;

RI – Random Index;

L_{max} – Largest Eigen Value.

The final computed weights help to define how response objectives are prioritised in the response planning stage. The pair-wise comparison method (known as Multi-criteria Analysis) is proposed as response priorities are acknowledged to be defined by a set of intangible variables (e.g. physical environment, resources availability, training skills, future projections). Comparing priorities among the participants will help us in finding whether or not response plans have common objectives. If planning patterns are found, we will be able to investigate pre-conceived ideas as well criteria used to define shape response planning.

The participant's perception of the situation is also analysed based on behaviour during the simulation exercise. This is commonly referred as situation awareness in the decision-making theory and consists of a three level process, i.e. perception of elements, comprehension of current situations and future projections (Endsley, 1995). The observation aims at acquiring unstructured data so we can analyse the how the participant's situation awareness develops over time. Situation Awareness Indicators such the ones proposed by McManus (2008) are intended to be used depending upon the quality of available data. The author analyses organisation's awareness in terms of operational environment, threats and opportunities, connectivity and relation with stakeholders. Similarly, we propose a set of five indicators to examine individual situation awareness in the context of the board game simulation:

- a) SA₁ – Roles and Responsibilities: participant's role during emergency events;
- b) SA₂ – Hazards and Vulnerabilities: consequences associated with particular events;
- c) SA₃ – Internal Response Priorities: organisation's internal priorities and participant's awareness of them;
- d) SA₄ – External Response Priorities: external organisations' priorities in the context of emergency management; and
- e) SA₅ – Connectivity: intra and inter-organisational communication procedures for information dissemination and technologies.

2.3.2. Step II – Decision Making Response:

The deployment of physical resources is analysed for each response day in order to understand how decision making was actually performed during the simulation. Additionally, the analysis of virtual resources (i.e. the proportion that each resource unit deployed to a specific site contributes to response objectives listed in the Importance Matrix) is performed so the response can be holistically comprehended. A combined analysis of physical and virtual resources aims at comparing response planning profiles (identified in the previous step) with actual response as virtual resources indicate how actual response aligns with planning. It is ultimately the comprehension of the decision making Physical Domain in which resources are moved in time and space in order to attend response needs posed by the evolving event (Cheah *et al.*, 2000) and priorities previously defined by the decision maker. Qualitative data is also used to support the analysis of response.

2.3.3. Step III – Decision Making Score:

A final performance indicator is estimated according to response priorities and proportion of resources deployed to specific response objectives (previously defined as virtual resources). It is a function of the response profile identified in Step I and the response observed in Step II. Equation 2 describes the mathematical function defined to estimate the score which ultimately depends upon the unique set of goals/objectives highlighted in the response profile.

$$Score = 1 - \left[\sum_{i=1}^8 (W_i - V_i) \right] \text{ given that } (W_i - V_i) > 0 \quad (2)$$

Where: i – Response objectives as presented in the Importance Matrix;

W_i – Estimated priority weights for each response objective;

V_i – contributing resources for each response objective, i.e. Virtual Resources.

2.3.4. Step IV – General Findings:

Both response planning (Step I) and resources deployment (Step II) support us in defining

patterns, strengths and weaknesses in decision making. The score indicator numerically estimates how consistent actual response was in comparison with response priorities defined by the participant previously the simulation.

Qualitative data (i.e. the participant's reasoning for resources deployment and observation of activities performed during the simulation) should also be used in the analysis of decision making processes. Finally, information collected during the final interview helps in presenting and discussing general information on emergency planning and management.

The combination of both qualitative and quantitative data is a synergic approach for complex subjects such as extreme events decision making. We aim at the identification, discussion and validation of specific results regarding extreme events decision making. For instance, we expect to identify patterns in the way that participants plan response by using priority weights estimated, to study the consistency on planning and responding by comparing response priorities and number of resources deployed targeting each objective, etc. Ultimately, strengths / weaknesses, concepts, models, techniques, knowledge, etc used during the management of emergencies in the context of transport networks will also be presented and discussed.

3. CASE STUDY

A set of six simulation exercises were conducted to assess how the proposed method can be applied to understand decision making-during disasters affecting transport systems. The following sub-sections describe the simulation scenario and the case studies results.

3.1 Simulation scenario

The emergency exercise simulation comprises the board game shown in Figure 1 and injects (or information) about the event. We simulate a five day response to an Earthquake disaster affecting a city with approximately 130,000 people. Five sets of injects were created representing the available information for each response day. Additional information can also be acquired by making enquired to the exercise controller.

The board game presents an urban environment composed by a number of features such as residential areas, industries, critical systems (power and water), Central Business District, hospital, stadium, airport and etc. The road network is represented by both highway links and local roads. It ultimately simulates particularities observed in practice, e.g. alternative or single accesses, major infrastructures and critical links.

Injects were designed in order to realistically simulate information flows observed in real earthquake situations. They describe the situation (i.e. the earthquake itself) along both technical and non-technical information. Initial damage is reported in the first response day; however information is still vague due to the chaotic environment created in the immediate aftermath. As time progresses, information gets more precise in terms of experienced damage, resource needs, priorities and communications culminating with field assessments therefore specific information.

The combination of board-game, injects and controller's familiarity with the scenario creates a very synergic simulation. Ultimately, a dynamic evolving experiment is developed so comprehensive data sets can be collected for future decision-making analysis.

3.2 Step I – Decision Making Planning:

Participants filled Importance Matrixes prior the simulation. Figure 3 shows the respective estimated priorities for each individual. Overall, participants have shown that people's rescue comprised the highest priority in their response planning. It ultimately represents a number of possible actions to be taken in order to maintain road accessibility to people and services such as ambulance, civil defence, Units of Search and Rescue and etc. "Enable Support from other Areas" was given the second highest priority. This is motivated by the possible need for external resources like food, water, clothing and response gear (machinery, fuel, materials).

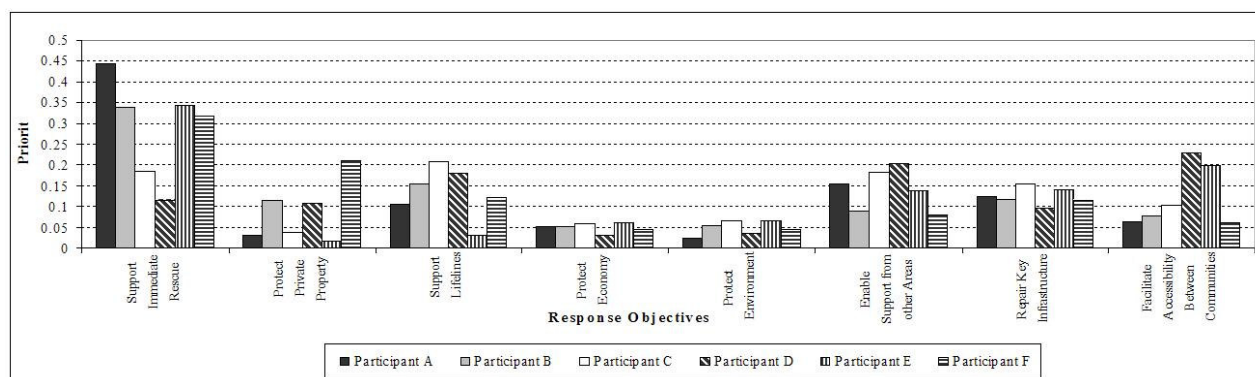


Figure 3: Response priority.

Other response objectives, such as Support Lifelines, Repair Key Infrastructure and Accessibility Between Communities, were ranked as middle priorities. This can be explained by the need to incorporate flexibility in the management process as disasters unfold and unexpected events might imply the need to quickly change response. At low priority levels, we found Protect Environment, Protect Economy and Protect Private Property. This fact can be associated with recovery processes as these objectives play vital roles at longer terms. Finally, an interesting phenomenon happens when environmental issues rise. Although they are considered as a low priority, shifts in response constantly occurs when the environment can be badly affected therefore jeopardise the availability of key resources (e.g. water).

Despite the general prioritization trend presented in the previous paragraph, two participants (C and D) presented Consistent Ratios (CR) well out of the acceptable limit proposed by Saaty (1994). Their CRs were respectively -0.04 and 0.68 and two reasons are used to explain such inconsistency: i) both participants struggled to fill the matrixes due to misunderstandings on the multi-criteria process and ii) They misjudged the importance of Support Immediate Rescue as remaining priorities for others objectives cannot be classified as proper outliers. Finally, both reasons are justifiable as the participants had indeed a very comprehensive understanding of the scenario and their behaviour was compatible with experienced managers.

Situation awareness could not be systematically analysed using the proposed set of indicators due to the limited number of case studies. Although the indicators were not properly applied, we observed that most of the participants get familiar with the environment by observing and analysing the board game. Questions about communities or existing hazards were commonly asked. They also engage in understanding their role during the simulation along with communication processes and resources availability. It is clear that participants develop their situation awareness as elements are perceived, current situations analysed and future projections estimated.

3.3 Step II – Decision Making Response:

Participants' actions in terms of resources deployment were recorded and summarized as shown in Figure 4. Two major response patterns were clearly identified: i) preserving arterial routes (i.e. links 1, 14 and 4), which give immediate access to the city and external regions and ii) ensuring local mobility and network connectivity for public and emergency services.

In this regard, some participants initially focused on responding events occurred at major arterial routes, some deployed resources at local roads for immediate rescue. In spite to differences, both approaches have the aim to support people and ultimately save lives. It is acknowledged that effects on people can be reduced by providing the best possible operational network (i.e. good balance between major accesses and local roads) in order to engage a speedy and effective response. This two-objective approach (deployment of resources towards major and local routes) only experiences changes when critical systems such as power or water supply can be badly affected. This is the case of the second day, when the Power Station starts to run at reduced levels. Resources are also deployed to manage the environmental issues posed by chemical spilling from industrial area due to possible contamination of water supply, but this was done with low priority.

Interestingly, participants applied comprehensive strategies to manage the emergency situation. Resources deployments were never focused on few sites, but instead followed a well strategized plan in which assets were gradually re-opened. Main focus was given to public rescue and evacuation at the initial response days. Priorities were then gradually shifted into recovery of critical systems (power and water) as people would possibly be running out of basic resources after the third day. It is clear that the participants were able to balance resources priorities from a great range of sectors (e.g. public, critical systems, businesses). It proves that emergency management is intrinsically dependent on events unfold, specific situations faced and individual organisations responsibilities and roles.

We finally estimated the number of resources contributing to specific response objectives. Defined as “virtual resources”, they indicate how participants aimed at achieving the response objectives defined in the Importance Matrix. They were estimated by a weighting system (not made available to participants) developed when designing the game. The results indicate that resources were deployed to provide road accessibility to the public and/or rescue services. Participant A had both link 1 (access to the other city) and link 14 (bridge over the river) operational in the third response day as his target was to maintain arterial roads open. Participant B's response indicates a longer response pattern focusing on both local and major routes. Overall, it was observed that majority of resources were deployed aiming at supporting immediate rescue, followed by either enabling external support or lifeline recovery.

Table 2: Contributing resources towards response objectives (Virtual resources).

	Support Immediate Rescue	Protect Private Property	Support Lifelines	Protect Economy	Protect Environ.	Enable Support from other Areas	Repair Key Infrastruct.	Facilitate Accessibility Between Communities
Part. A	21.5	4.8	10.8	4.8	2.4	8.5	3.8	2.4
Part. B	22.4	3.9	12.2	1.8	0	9	8.1	1.6
Part. C	13.4	1.9	10.8	5.5	2.7	5.6	7.7	2.4
Part. D	19.9	4.5	10.8	4.3	2	1	5.1	2.4
Part. E	20.3	3.4	2.2	4.2	1.2	11	6.3	4.4
Part. F	17.3	4.2	7	4.3	2.8	8	6.4	0

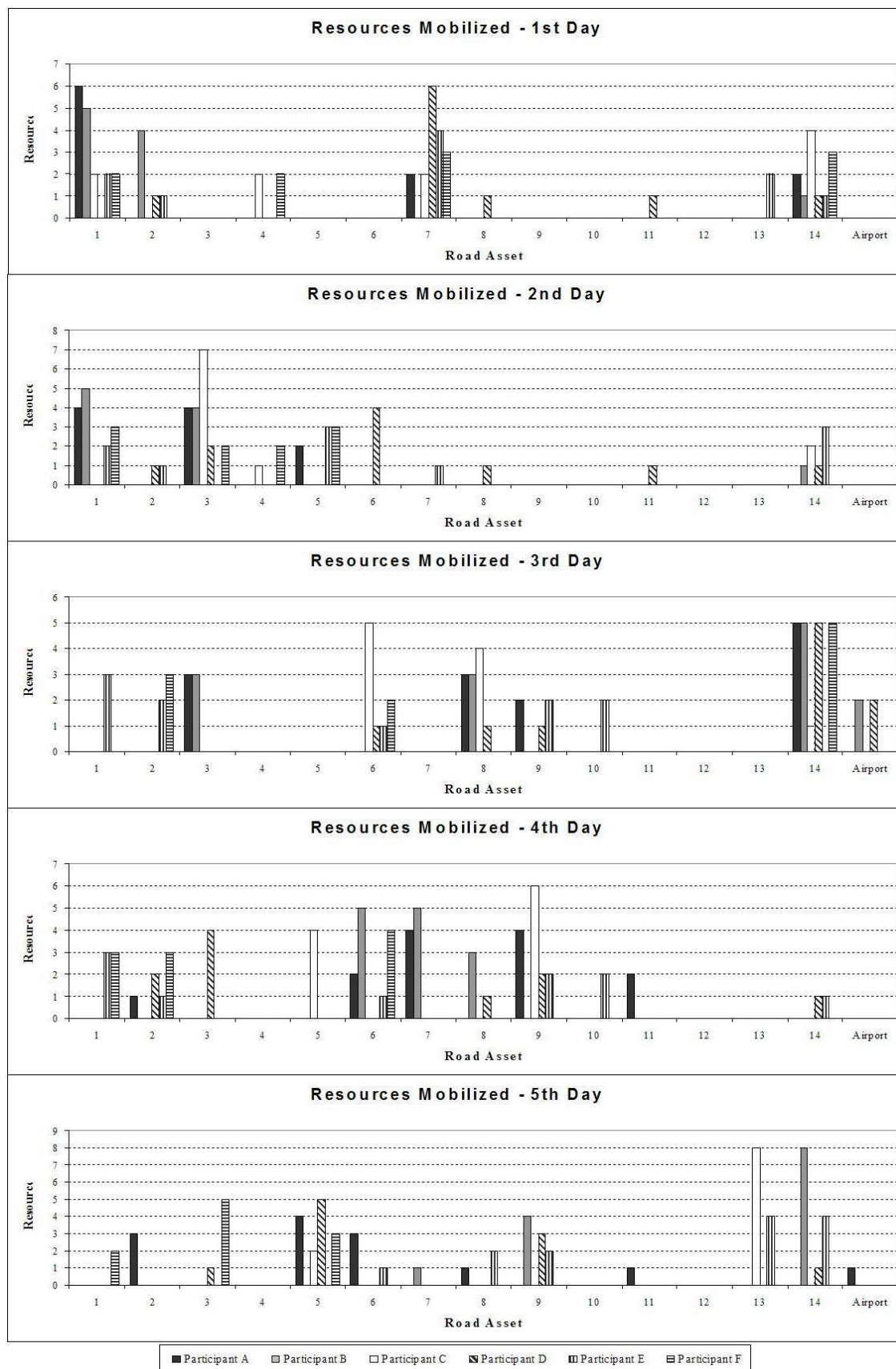


Figure 4: Resources mobilized daily.

3.4 Step III – Decision Making Score:

Participants had similar performances in terms of resource allocation. Table 3 shows Decision-making Scores values for each participant. Both highest and lowest values (Participants C and D) need to be consistently analysed as score is dependent on the Response Profile and these two participants had low Consistency Ratios. Although their simulations were initially considered, we reinforce that these results should be carefully used for final analyses as it considers the whole simulation process, i.e. Decision Making Planning and Decision Making Response).

Table 3: Decision making scores.

	Participant A	Participant B	Participant C	Participant D	Participant E	Participant F
Score	0.83	0.82	0.86	0.62	0.82	0.81

Results shown in Table 3 indicate that participants' decision-making planning was consistent with response actions. Thus, a rational decision-making process is identified. Participants attempted to maintain a clear set of objectives when responding to emergencies by using their experience and knowledge as well as considering external organisations or public needs and events unfold. During the final interview some participants made clear that emergency managers should deeply consider external needs as roading organisations have to support a number of response activities. This finding confirms that under networked environments, organisations should operate considering a whole set of interconnected organisations according to the community served and stakeholders (McManus, 2008). Specifically for roading organisations, numerous organisations depend on the road network to conduct their own response activities (AELG, 2005). Finally, concepts such as risks and cost-benefit analysis were often cited as being part of extreme events decision-making.

3.5 Step IV – Decision Making Process:

Well-structured decision-making patterns can be identified using both quantitative and qualitative data. As illustrated in Figure 5, participants used a set of knowledge and experience in order to project future consequences from their decisions at early response stages. This process aims at reducing the total number of response alternatives (i.e. physical deployment of resources). Finally, projected consequences are analysed by a satisfying process according to established priorities and goals/objectives in order to support final decisions.

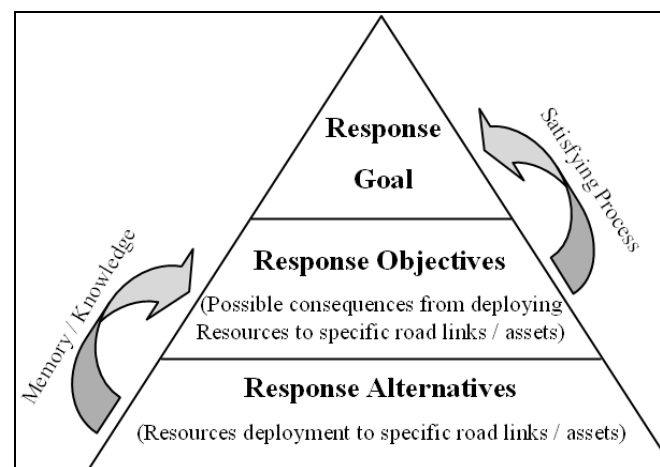


Figure 5: Observed decision making structure during disasters.

Additional findings from the simulations are reported as follows:

- Different community expectations were met by spreading resources over many locations. For instance, participants did not deploy at once too many resources to Road Link 1 regardless a possible increase of 30% in resources after fixing this particular link;
- Supporting communities was the highest priority during initial response days. The response priority was then shifted into a community / critical systems support after the second or third response day. The need for resources is critical in the immediate initial aftermath of the event as people, hospitals and shelter facilities might be running out of basic resources such as water and power;
- Emergency response was clearly a goal-oriented and time-dependent process as participants have defined goals according to the length of time of the simulation. Some participants stated in the final interview that, despite not been able to fix a great number of assets, they were satisfied with their performance as most of key infrastructure issues tackled during the simulation would probably be solved in a short period of time after the fifth response day;
- Response planning, as shown in the Importance Matrix, guides rational decision-making processes. Participants remain focused on objectives defined previously the simulation. Emotional disturbing information (e.g. great number of people trapped in Residential Area 1) did not potentially change response;
- Improvisation plays a key role in the response. Changing information in the scenario forced decision makers to re-assess planning and goals and search for alternative strategies. For example, participants adapted their response strategy when the power plant needed access or the main bridge over the river nearly collapsed due to high traffic volumes;
- A multiagency approach has been observed as participants either enquired for external priorities or made clear that particular responses were motivated exclusively due to external organisation's needs. Organisational cooperative responses have been usually observed during major disasters (e.g. 9/11 Attacks, 2005 Sumatra Earthquake and Tsunami). Real events observations also point to lack of communication and joint response as causes of major deficiencies in emergency management (Bahora *et al.*, 2003; Ntuen, 2006; Runyan, 2006; Titan Systems Corporation, 2002 *apud* McManus, 2008);
- Basic assumptions were generally used during the response. For instance, one participant assumed that the rail way link was operational up to the Development Site; therefore resources would not be deployed to fix the railway bridge. However, no information was given on this matter nor asked by the participant;
- Some participants did not fully comprehend the physical environment. One participant was not able to get familiar with the board although reasonable time for familiarization was given. In this particular case, the participant realised only at the end of the simulation the location of the stadium where homeless people have been directed since the first response day; and
- Decision-making motivated by uncertain resources needs were taken at some instances due to potential severe consequences of damage, e.g. participants deployed resources to Link 5 (industrial area) in order to support fire fighting although needs were not confirmed. Such response actions can be associated with expert situational assessments, which consider assets' importance and estimates future operational consequences in the network due to disruptions.

4. CONCLUSIONS AND FUTURE RESEARCH

This paper presents a novel method to analyse decision-making during extreme events. Based on Decision-making Theory, a data collection framework and an analysis method were conceptualized. The method evaluates participant's actions in order to identify decision-making patterns, strengths and weaknesses.

The game-based scenario simulation has proven that realistic and complete data sets can indeed be collected. The proposed analysis method has helped us to frame decision-making processes according to a set of general principles. It also indicated the Naturalistic Decision-Making as the most suitable model for extreme events as decisions are made using processes of situation recognition and pattern matching to memory structures and prototypical situations (Dreyfus, 1981 and Sweller, 1988).

A set of case study simulations shows that there are two typical patterns, namely: a) Support immediate rescue activities; b) Support lifelines recovery. The analysis of the simulations' results indicates that participants demonstrated a great focus on providing people and emergency services (e.g. ambulance, police) with an operational network so commuting is possible. During initial stages, resources are deployed either to major infrastructure or the local network depending on specific event's characteristics, the physical environment and emergency under management. Priorities then shift into critical systems recovery as basic needs and resources are usually needed at short terms in the aftermath of disasters.

It is acknowledged that roading organisations do have to follow priorities set by external organisations so response actually regards in balancing conflicting priorities accordingly to available resources. This is a multiagency approach, which also creates multi-objectives tasks. Therefore, complex technical knowledge and experience need to be considered before any major decision can take place. A strict approach of right or wrong decisions is usually not accepted by transport managers as response cannot be rigidly modelled neither affirmed. Response has the aim to restore network operationability as soon as practical according to different needs and priorities (e.g. great number of injuries, accessibility to treatment facilities / hospitals, economic impacts, major infrastructure disruptions and business continuity). Hence, extreme events decision-making is mutually dependent on resources availability and resources needs. Participants clearly demonstrated that resources availability and needs are parallelly assessed in order to support defining final decisions.

Future research should aim at developing supporting tools for roading organisations using the findings achieved in this study. We currently envisage a dynamic system, which progressively incorporates data from emergency events along with static studies about the roading system and lifelines. The system will ultimately process both dynamic and static data in order to prompt response recommendations to transport managers so decision making can be facilitated, response times reduced and information better shared. Initial research has indicated that flexible systems should be designed in order to avoid redundancy (Stanton and Baber, 2006) therefore performance limitation (Endsley *et al.*, 2003). Finally, the proposed game simulation has shown potentials to be used as a training tool due to positive participants' assessments regarding the complexity of scenario and simulation of emergencies as well its low cost to be developed and implemented.

REFERENCES

- AELG – Auckland Engineering Lifeline Group (2005). Resources Available for Response and Recovery of Lifeline Utilities. **Technical Publication No. 282 (Version 1.0). ISBN: 1-877416-02-9. Auckland Regional Council, Auckland, New Zealand.**
- Cheah M., Ngoh C., Fong G., Toh E., (2000). NWC in Action – Experimentation within a Distributed and Integrated Command Environment. **Proceedings of 12th International Command and Control Research and Technology Symposium. June 19-21, 2007, Newport, Rhode Island, USA.**
- Cherrie W.W. Ng & Dickson K.W. Chiu (2006). E-Government Integration with Web Services and Alerts: A Case Study on an Emergency Route Advisory System in Hong Kong. **Proceedings of the 39th Hawaii International Conference on System Sciences. Kauai, Hawaii.**
- Dreyfus S. E. (1981). Formal models versus human situational understanding: Inherent limitations on the modelling of business expertise (ORC 81-3). **Berkley: Operations Research Center, University of California.**
- Endsley, M. R. (1995). Toward a Theory of Situation Awareness in Dynamic Systems. **In Human Factors, 37(1), 32-64. Copyright 1995 by the Human Factors and Ergonomics Society.**
- Endsley, M. R., Bolté, B. Jones, D. G. (2003). Designing for Situation Awareness: An Approach to User-Centered Design. **London: Taylor & Francis.**
- Ferreira, F. Dantas, A. Seville, E. (2007). Conceptual Dynamic Response Recovery Tool for Emergency Events. **Third International Forum on Engineering Decision Making (IFED): "Optimal strategies for disaster and hazard mitigation". 12th to 15th December 2007. Port Stephens, NSW, Australia.**
- Fong, G. (2006). Adapting COTS Games for Military Experimentation. **Simulation and Gaming, Vol. 37 No. 4, December 2006, pp. 452-465. DOI: 10.1177/1046878106291670. SAGE Publications.**
- Fu, L. Sun, D. Rilett, L. R. (2006). Heuristic shortest path algorithms for transportation applications: state of the art. **Computers and Operations Research, Volume 33, Issue 11 (p. 3324-3343). ISSN.: 0305-0548. Elsevier Science Ltd.**
- International Federation of Red Cross and Red Crescent Societies (2002). **World Disasters Report: Focus on Reducing Risk. Bloomfield, CT, Kumarian Press.**
- Kagaya, S. Uchida, K. Hagiwara, T. Negishi, A. (2005). An Application of Multi-Agent Simulation to Traffic Behaviour for Evacuation in Earthquake Disaster. **Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 4224 – 4236.**
- Liu, B. (1997). Route finding by using knowledge about the road network. **IEEE Transactions on Systems, Man and Cybernetics, Part A, Volume 27, Issue 4 (p. 436-448). ISSN: 1083-4427.**
- Liu, H. X. Ban, J. X. Ma, W. Mirchandani, P. B. (2006a). Model Reference Adaptive Control Framework for Real Time Traffic Management under Emergency Evacuation. **Proceedings of the 85th Annual Meeting of the Transportation Research Board (CD-ROM), Washington.**

- Liu, Y. Lai, X. Chang, G. (2006b). A Cell-Based Network Optimization Model For Staged Evacuation Planning Under Emergencies. **Proceedings of the 85th Annual Meeting of the Transportation Research Board (CD-ROM), Washington, D.C.**
- McCarthy, D. Curran, S. Byron, S. (2005). The Art of Producing Games. **The Ilex Press Limited. ISBN 1-59200-611-6.**
- McManus, S. T. (2008). Organisational Resilience in New Zealand. **A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Civil Engineering at the University of Canterbury. University of Canterbury, Christchurch, New Zealand.**
- Mendonça, D. Beroggi, G. E.G. Wallace, W. A. (2001). Decision support for improvisation during emergency response operations. **International Journal Emergency Management, Vol. 1, No. 1, 2001.**
- Mendonça, D., G. E. G. Beroggi, D. van Gent and W. A. Wallace (2006). Assessing Group Decision Support Systems for Emergency Response Using Gaming Simulation. **Safety Science 44(6) 523-535.**
- Mendonça, D. and W. A. Wallace (2007). A Cognitive Model of Improvisation in Emergency Management. **IEEE Systems, Man and Cybernetics: Part A, 37(4) 547 – 561.**
- Saaty, T. L. (1980). The Analytic Hierarchy Process. **New York, N.Y., McGraw Hill. Reprinted by RWS. Publications Pittsburgh, 1996.**
- Saaty, T. L. (1994). How to Make a Decision: The Analytical Hierarchy Process. **Interfaces 24(6), 19 – 43.**
- Sweller J. (1988) Cognitive load during problem solving: effects on learning. **Cognitive Science. Vol. 12, pp. 257-285.**
- Stanton, N. A. Baber, C. (2006). The Ergonomics of Command and Control. **Ergonomics. 49(12-13): 1131-1138.**
- Takeuchi, T. Kondo, A. (2003). Allocation Analysis for 'Earthquake Tsunami Refuge Facilities' by Maximizing Successful Passage. **The 8th International Conference on Computers in Urban Planning and Urban Management Conference. Tohoku University, Sendai.**
- The Virginia Department of Emergency Management (2001). School Crises Management: Exercise Development Guide. **<http://www.vdem.state.va.us/prepare/schoolcrisisguide.pdf>. Last accessed 24 October 2008.**

Revision Report

Paper ID: 100394

Paper title: Extreme Events Decision Making in Transport Networks: A Holistic Approach Using Emergency Scenarios and Decision Making Theory

Contact author: Frederico FERREIRA

No.	Requested revision level	Location		Reviewer's comment/request/question	Your resulting revision
		Page no.	No. of line/figure/table		
1	Required	Throughout the paper		Grammar and expression should be improved so that the paper can be clearly understood.	A series of reviews were made all over the paper in order to correct grammar mistakes as well to clearly present concepts and ideas. They are not specifically reported here due to a great number of minor changes performed in the text.
2	Required	1, 4 and 14		In the Abstract, the paper mentions two typical patterns, support search and rescue and enable critical system recovery, before they appear again in the first paragraph of Chapter 3.3, some explanation are needed...	Initially, terminologies for both "support search and rescue" and "enable critical system recovery" were changed for "support immediate rescue activities" and "support lifelines recovery", respectively. Although they represent same objectives, changes were made in order to achieve accordance with the initial nomenclature proposed by the Importance Matrix. Finally, a brief explanation about each response objective defined in the Importance matrix was added at page 4 to support the reader in understanding why we have taken such approach.
3	Non required (decided by authors)	4			The whole paragraph before the importance matrix was reviewed and changed for clear presentation of ideas regarding the importance matrix filling process and role at the simulation.
4	Non required (decided by authors)	4	Table 1		The Importance Matrix table has been replaced by an improved version of itself.
5	Required	6	Figure 2	There are four steps in this method, it will be much better if a flow chart is used to describe the relationship among the four steps...	A chart has been included (Figure 2) and the relations among phases properly explained. Descriptions for steps I, II and IV were slightly modified due to space constraint.

6	Required	9		Grammar and expression should be improved [...] especially in Chapter 3.2 (analysis process).	A number of changes has been made in order to clearly present the analysis of data collected by Importance Matrixes.
7	Required	9		In Chapter 3.2, the "outcomes of the first three steps" is presented with five aspects. A brief explanation of these results is needed...	Comment not found in original text. Nonetheless, the whole chapter 3.2 has been reviewed in order to present ideas in clearer formats.